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ORIGINAL PAPER

Oxalate, magnesium and calcium content in selected kinds of tea: impact on human health

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Abstract The aim of the study was to determine oxalate content in black, dark and green teas as well as to estimate the content ratio of Mg to Ca in tea infusions that is significant for patients with kidney stones. Atomic absorption spectrometry was used to determine Ca and Mg, while oxalate was analyzed by manganometric method. The highest levels of oxalate were found in black and dark tea (156 and 224 mg/200 mL, respectively) and the lowest in green tea (80 mg/200 mL). The greatest degree of leaching to tea infusions was determined for Mg in green (37 %) and black tea (34 %). The lowest percentage of leaching was estimated for Ca (7 %) in black tea. It was concluded that people with hyperoxaluria or a tendency to form kidney stones should consume tea, especially this of darker color, in moderate quantities.

Keywords Magnesium · Calcium · Oxalate · Tea · Kidney stones

Introduction

Tea is one of the most consumed beverages all over the world [1]. There are two species of *Camellia sinensis*: var. sinensis and var. assamica [2, 3]. There are different types of tea produced from fresh tea leaves (*C. sinensis*) [4]. Due to the used processing, the following types of tea can be distinguished: black (fully fermented leaves by oxidizing enzyme), green (non-fermented leaves), oolong (semi-fermented leaves) and dark tea such as Pu-erh (post-fermented leaves by microbes) [5]. Black tea undergoes several hours of full oxidation before steaming and drying, whereas oolong teas undergo partial oxidation; in contrast, green teas are not exposed to any oxidative process [6].

Based on the available scientific literature, it can be stated that drinking tea has a significant impact on human health [15]. It has been shown that tea exhibits anti-oxidative power as well as anti-Alzheimer's effect, and its components also play role in reducing blood pressure and obesity prevention [16]. Besides being health-promoting, tea also contains anti-nutritive compounds such as oxalate. Soluble oxalates are able to bind Ca and other minerals in acidic to near-neutral conditions, what makes these elements unavailable to the human organism [17].

Liebman et al. [7] reported that tea oxidation leads to the generation of oxalate because the concentration of oxalate is the highest in black teas, intermediate in oolong teas and the lowest in green teas. Moreover, different parts of the same tea plant can contain various levels of oxalate, with younger parts richer in oxalate than the older ones [8]. Black and oolong teas are made from older leaves, and green tea from the flush-containing young leaves [9–11]. Honow et al. [12] concluded that the oxalate content in green tea may vary with time of harvest. Leaves reaped in the autumn, when grown to full size, yielded more oxalate than small and young leaves reaped in the spring. What is more, Morita et al. [13] reported that increasing ammonium in the hydroponic growing media decreased oxalate content in tea plants. The concentration of oxalate can be also changing depending on the time of storage [14].

The bioavailability of oxalate from tea is estimated at 1–9 % [7]. Oxalate absorption occurs mainly in the intestine through trans- and extracellular way. The highest concentration of oxalate in urine was observed 2–6 h after food

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Table 1 Characteristics of analyzed products

Lp.	Name of tea	Producer	Confection	Origin
Green tea				
1.	Saga (green tea)	Unilever Poland S.A.	Bags	Not declared
2.	Vitax Inspirations	Vitax—Multeafil	Loose	Not declared
3.	Green Leafy	Herbapol Lublin S.A.	Loose	Not declared
4.	Tetley Classic	Tata Global Beverages Polska	Bags	India
5.	Green Tea	Carrefour Poland	Bags	Not declared
6.	Green Tea with the quince fruit	Bio-Active Dystribution	Loose	China
7.	Irving™ Green Superior	Kamis S.A.	Loose	Not declared
8.	Dilmah-Green Tea Sencha	Dilmah—MUF Holdings Ltd.	Bags	Sri Lanka
9.	Teekanne Green Tea	Teekane Poland	Bags	Not declared
10.	Lipton Green Tea Classic	Unilever Poland	Bags	Not declared
Black tea				
11.	Minutka	Mokate S.A.	Bags	Not declared
12.	Sir Roger Earl Grey	Roger S.A.	Bags	Sri Lanka
13.	Saga (black tea)	Unilever Polska S.A.	Bags	Not declared
14.	Twinings™ Prince of Wales	Twinings™—AB Food Polska	Bags	China
15.	Tetley	Tata Global Beverages Polska	Bags	India
16.	Yunnan (peach and apricot)	Big Active	Loose	Not declared
17.	Dilmah Premium Tea Ceylon Orange Pekoe	Dilmah—MUF Holdings Ltd.	Loose	Sri Lanka
18.	Loyd Earl Grey	Mokate S.A.	Loose	Not declared
19.	Irving™ Daily Classic	Irving™—Amber Spark S.A.	Bags	Not declared
20.	Lipton Yellow Label Tea	Unilever Polska S.A	Bags	Not declared
Dark tea				
21.	Sir Roger Pu-Erh	Roger S.A.	Bags	China
22.	Irving Tea Spa perfect slim	Kamis S.A.	Bags	Not declared
23.	Vitax Pu-Erh&Grapefruit	Vitax—Multeafil	Bags	Not declared
24.	Teekane Pu-Erh Tea Lemon	Teekane Poland	Bags	Not declared
25.	Carrefour Tea	Carrefour Poland	Bags	China
26.	Pu-Erh Lemon	Bio-Active Dystribution	Loose	Not declared
27.	Pu-Erh China Leafy	Astra Poznanska Coffee Roaster—Astra	Loose	Not declared
28.	Pu-Erh Grapefruit and orange	5'o clock Tea and Coffee shops	Loose	China
29.	Pu-Erh Superior	5'o clock Tea and Coffee shops	Loose	China
30.	Pu-Erh Yunnan	5'o clock Tea and Coffee shops	Loose	China

intake [18]. The effect of oxalate excess in the human body may result in the formation of kidney stones that are insoluble deposits in the urinary tract. This process occurs mainly due to precipitation of chemical substances in the urine when their concentration exceeds solubility limit [19, 20].

Since a continuous increase in the incidence of kidney stones can be observed, it is necessary to consciously control daily diet. It is especially important for patients with a high risk of kidney stones development and other diseases dependent on the oxalate intake such as renal failure or urinary tract infection [21].

The aim of this study was to determine oxalate, magnesium and calcium concentrations in black, dark and green tea and their percentage of leaching to infusions. Furthermore, it was possible to evaluate the content ratio of Mg to Ca which is significant for patients with kidney stones. The obtained results allow assessing which species of tea is suitable for consumption by patients with this disease.

Materials and methods

Sample material

The analyzed tea samples were purchased from markets in Gdańsk (Poland). There were 270 analytical samples prepared in which oxalate, Mg and Ca (in leaves and tea infusions) were determined (Table 1).

Table 2 The concentration of oxalate, magnesium and calcium in mg ($\bar{x} \pm$ SD, range) per 200 mL of tea infusion, the percentage of leaching (%) and realization of RDA through consumption of 200 mL of infusion (%)

Tea	*n*	Oxalate mg/200 mL	Mg mg/200 mL	RDA of Mg[a] (%)	Percentage of leaching Mg (%)	Ca mg/200 mL	RDA of Ca[b] (%)	Percentage of leaching Ca (%)
Green tea	9 × 10	80 ± 5.2 (49–139)	1.68 ± 0.52 (0.89–2.52)	0.40/0.52	37	0.31 ± 0.04 (0.02–1.5)	0.03	14
Black tea	9 × 10	156 ± 18 (51–304)	4.39 ± 1.31 (1.29–5.67)	1.04/1.37	34	3.54 ± 2.37 (1.39–13)	0.35	7
Dark tea	9 × 10	224 ± 16 (122–342)	1.48 ± 0.21 (1.14–1.82)	0.35/0.46	23	1.51 ± 1.17 (0.22–4.70)	0.15	15

[a] RDA for Mg for males (31–50 years) is 420 mg/day/person and for females (31–50 years) is 320 mg/day/person [45]

[b] RDA for Ca for males (31–50 years) and females (31–50 years) is 1000 mg/day/person [45]

Preparation of samples

About 10 g (±0.0001 g) portions of homogenized products were weighed, and dried material was transferred to quartz crucibles and ashed in an electric furnace (540 °C). Tea brew was prepared from 2 g (±0.0001 g) portions of homogenized products and 200 mL of water and infused for 5 min. Then, the solution was filtered, evaporated to dryness on a boiling water bath and ashed in an electric furnace. The ashed material of tea leaves and tea infusions was mineralized by a mixture of concentrated acids [22].

Analysis of macroelements

Such prepared solutions were analyzed by AAS using Thermo Scientifics i3000. In case of Mg and Ca, 0.4 % w/v lanthanum oxide was added (lanthanum (III) oxide, Merck, Darmstadt, Germany) as a correction buffer.

Analysis of oxalate

To determine oxalate, 3 g tea samples were weighed and treated with 100 mL of water (5 min infused). Ten milliliters of solution was transferred to centrifuge tubes and 5 mL 5 % $CaCl_2$ and 5 mL acetone were added. Then, solutions were cooled at 5 °C for 30 min and centrifuged for 15 min (3000 rot/min). The sediment was transferred to the flask with 5 mL 10 % H_2SO_4 and heated on a water bath (70 °C) until dissolution. Then, it was immediately titrated with a standard solution of $KMnO_4$.

Validation of method

Reliability of the method was checked using the certified reference materials (Tea, NCS ZC73014 and Tobacco INCT-PVTL-6). Recoveries of the studied elements ranged between 86 and 96 % for tea and 107 and 109 % for tobacco. Precision of the method ranged between 1.6 and 4.4 % for tea and 2.3 and 6.0 % for tobacco.

Results

Oxalate

The highest average oxalate level was determined in dark tea (224 mg/200 mL), followed by black tea (156 mg/200 mL) and green tea with its lowest levels (80 mg/200 mL) (Table 2). The highest oxalate level was determined in dark tea Pu-Erh Superior 5'o clock—342 mg/200 mL. Among black teas, Sir Roger Earl Grey had the highest levels of oxalate (304 mg/200 mL). The lowest levels of oxalate were determined in green tea with quince fruit—Bio-Active (49 mg/200 mL). Among analyzed tea samples, green tea characterized with the lowest oxalate content, which was in agreement with results reported by Michalak-Majewska [23]. Comparable results were published by Sperkowska and Bazylak [24] for black tea (178 mg/200 mL) and Rusinek [25] for dark tea (204 mg/200 mL). However, according to Rusinek [25], average content of oxalate in black tea infusions was lower and amounted to 116 mg/200 mL. According to Sperkowska and Bazylak [26], oxalate content in green tea amounted to 110.2 mg/200 mL, which is comparable with results obtained in this study (Table 2). Charier et al. [27] found that non-fermented tea contains lower amounts of oxalate than the fermented one.

Macroelements

Tea elemental composition varies depending on the geographical origin of tea [28–30], genetic differences [31, 32], the composition of the local soil as well as its characteristics and various agricultural or climatic conditions [31–34]. The differences in elemental composition of tea plants

besides being related to concentrations of these elements in the soils are also dependent on metals' physicochemical forms [35]. What is more, it was implied by couple of authors that the variability in the elemental content of different brands of tea is common and much higher for black teas than for green teas, for which concentration ranges of elements are relatively narrower [35, 36]. According to Malik et al. [37], the macroelements and microelements levels in particular kinds of tea are not significantly varied, but black teas are usually richer in trace elements than other types of teas, mainly due to the specific way by which these teas are manufactured. In order to produce green tea, leaves are steamed with water vapor, and this process may lead to losses of some elements, whereas leaves for black tea are air-dried so there is not observed loss of elements [38]. Moreover, black and dark teas are usually produced from older leaves, containing higher concentrations of metals, than green tea made from the young leaves [9–11]. In our study, the levels of Mg and Ca were higher in black (4.4 mg Mg/200 mL, 3.5 mg Ca/200 mL) than dark (1.5 mg Mg/200 mL, 1.5 mg Ca/200 mL) and green teas (1.7 mg Mg/200 mL, 0.3 mg Ca/200 mL) (Table 2). Higher levels of Mg and Ca in green tea were reported by Malik et al. [37] (3.6 mg Mg/200 mL and 0.79 mg Ca/200 mL). However, Malik et al. [37] recorded lower amounts of the analyzed elements in black tea (3.2 mg Mg/200 mL and 0.5 mg Ca/200 mL). In case of dark tea, Malik et al. [37] reported lower contents of Ca (0.42 mg Ca/200 mL), but higher of Mg (2.0 mg Mg/200 mL). Comparable average levels of Mg and Ca in dark tea (1.24 mg Mg/200 mL and 1.8 mg Ca/200 mL) were published by Malinowska et al. [39].

Percentage of leaching

The extraction effectiveness of elements into tea infusions depends on whether they are strongly bound to the organic matrix or more soluble in the solution [40]. Most of the elements in tea leaves are complexed by flavonols, catechols, tannins and polyphenols [11]. With respect to this, better leaching of some essential macroelements and trace elements from leaves into infusions was reported for green teas rather than black and oolong teas [1, 33, 37, 41]. The variation in Ca extraction from the analyzed teas can be explained by the differences in plant's age at harvest or tea-growing conditions. Black and oolong teas are usually produced from older leaves than green tea made from the flush-containing young leaves [9–11].

In our study, magnesium characterized with the highest percentage of leaching, especially in green (37 %) and black tea (34 %) (Table 2). The latter is comparable with values reported by Dambiec et al. [42]. Calcium was poorly extractable (7–15 %), similarly to what was suggested by Szymczycha-Madeja et al. [35]. Gallaher et al. [43] reported lower percentages of extraction of Mg (19 %) in green teas, but comparable for Ca (7 %) (Table 2). In case of dark tea (23 % Mg and 15 % Ca), percentage of leaching was comparable for both of elements and similar to results obtained by Malinowska et al. [39] (29 % Mg and 17 % Ca).

Statistical analyses

The results were also analyzed by Spearman's ranks correlation analysis, Kruskal–Wallis test and cluster analysis (CA). First of all, the data were checked for normal distribution. In all of the analyzed cases, there was no normal distribution, and, therefore, nonparametric tests were applied [44].

Correlation analysis for the analyzed elements was performed at three levels of significance ($p < 0.05$, $p < 0.01$, $p < 0.001$). There were two positive correlations recorded ($p < 0.05$), i.e., between the kind of tea and Ca, and Ca–Mg. There was also recorded one positive correlation between the kind of tea and oxalate ($p < 0.01$).

The Kruskal–Wallis test showed statistically significant differences between the type of tea and Ca ($H = 19.12$, $p = 0.0001$), Mg ($H = 13.88$, $p = 0.001$) and oxalate ($H = 11.17$, $p = 0.004$). The cluster analysis (CA) was performed using Ward method and Euclidean distance. Figure 1a presents the dendrogram, which is built of three main clusters containing commercial samples of particular kinds of tea. It can be observed that CA made it possible to differentiate tea samples in view of tea type with respect to its content of oxalate, Mg and Ca. As it can be seen in Fig. 1b, Mg is responsible for the differentiation of green tea, which is consistent with its high content in this type of tea, as compared with the remaining components. Other kinds of tea, i.e., black and dark, were described by oxalate and Ca, respectively. Cluster analysis has proven to be a good tool for tea samples differentiation in terms of its components.

Recommended Dietary Intake

Recommended daily intake (RDA) was calculated for green, dark and black tea infusions according to the latest available Polish recommendations for males and females (31–50 years [45] (Table 2). RDAs for Ca are realized in the range of 0.03, 0.15 and 0.35 % by consumption of 200 mL of black, green and dark teas, respectively. Realization of RDA for Mg by green and dark teas (0.03, 0.03 %) was lower than by black tea (0.09 %). According to these results, it seems that none of the analyzed kinds of tea would be a good source of these elements. Oxalate results were assessed in view of recommendations of American

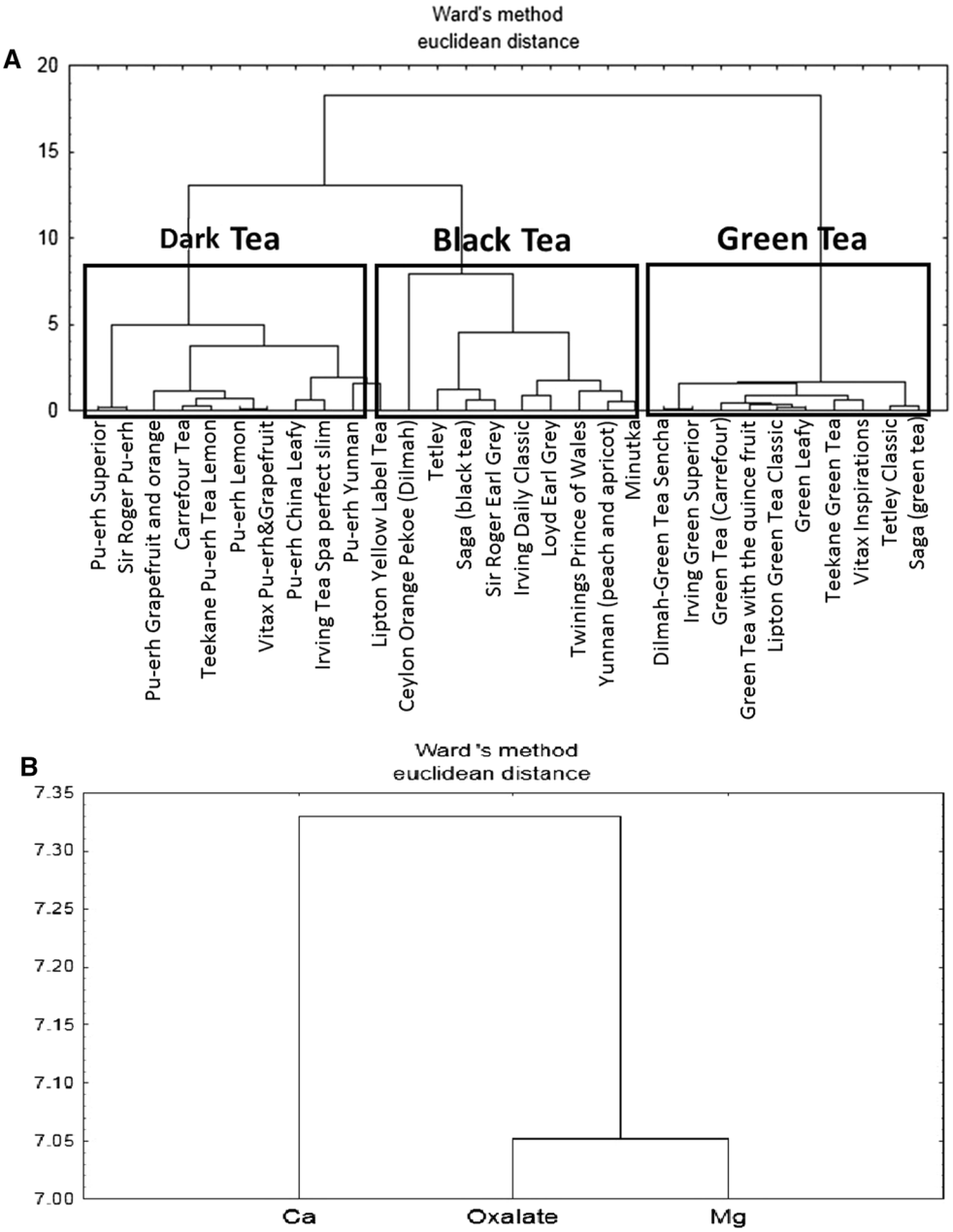

Fig. 1 **a** Hierarchical dendrogram for the analyzed tea samples as objects in view of the kind of tea. **b** Hierarchical dendrogram for the analyzed elements in tea samples in view of the kind of tea

Dietetic Association. According to them, the levels of oxalate for people with increased risk of kidney stones should not exceed 40–50 mg per day [46]. As people in Poland drink 2–3 times tea per day [47] and average bioavailability of oxalate is 9 % [7], so from three cups of green tea (240 mg/600 mL) there will be absorbed 22 mg of oxalate. In case of black tea (468 mg/600 mL), 42 mg of oxalate will be absorbed. Drinking on average three cups of dark tea (672 mg/600 mL) might result in absorption of 60 mg of oxalate. Therefore, it can be concluded that consumption of three cups of dark tea per day is more dangerous for people with risk of kidney stones than drinking the same amount of green tea. However, there are many anomalies in bioavailability and metabolism of oxalate in gastrointestinal tract, which could hinder the real estimate of oxalate absorption from tea [48].

Discussion

Bioavailability of studied components and health effects

Liebman and Costa [49] compared the effects of calcium carbonate and magnesium oxide on oxalate absorption. The results showed that Ca was more effective in oxalate absorption than Mg (62 and 44 %, respectively). About

three-fourths of all kidney stones are composed primarily of calcium oxalate. However, Mg is a cation which can form more soluble complex with oxalate, than Ca complex, and would be also predicted as a protective agent against kidney stones. Therefore, it is important to keep the correct content ratio of Mg to Ca. Mg has a higher affinity to oxalate, thus when Mg levels in diet are higher than Ca levels, it results in reduced ability of oxalate to crystallize in the stones [50]. As a consequence of reduced calcium oxalate level, formation of kidney stones in patients was not observed [51].

It was found that calcium salts contained in the urine do not crystallize due to the binding of about 80 % of calcium ions with citrates, gluconates, urea and amino acids [51]. Dark tea, analyzed in this work, had higher levels of oxalate and macroelements and, thus, it represents higher risk for patients, who are exposed to the development of kidney stones. The content ratio of Mg to Ca in the analyzed teas (especially in dark teas) was too low to protect against formation of kidneys stones. Therefore, it seems reasonable to use the pharmaceuticals with magnesium in treatment of kidney stones [52]. Also dietary calcium restriction has been a mainstay of therapy for the prevention of recurrent kidney stones [51]. According to Noonan and Savage [53], sporadic consumption of high-oxalate foods does not lead to adverse health effects. Patients particularly affected are those whose diet is not enough varied, with a predominance of products rich in oxalate. The lowest content of oxalate in green tea suggests choosing this kind of tea by patients with developed kidney stones and in prevention of this disease. Furthermore, Jeong et al. [54] showed that green tea, despite the presence of free oxalate, also contains epigallocatechin gallate, which acts to hinder the formation of kidney stones.

Conclusions

The complex composition of tea contributes not only to positive but also adverse effects of its consumption on the human body. The analyzed kinds of tea characterized with different oxalate contents. The highest levels of oxalate were determined in the analyzed samples of dark and black tea. Black tea characterized with higher content of Mg and Ca than other teas. However, the content ratio of Mg to Ca in the analyzed teas was too low to protect against the formation of kidneys stones; thus, it seems reasonable to use magnesium pharmaceuticals in treatment of kidney stones. Based on the results, it was confirmed that people with hyperoxaluria or a tendency to form kidney stones should avoid dark and black tea. The lowest content of oxalate in green tea suggests choosing this kind of tea, but it is only one of the products consumed, so it is necessary to consciously control daily diet in view of oxalate content.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical standards The manuscript does not contain clinical studies or patient data.

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